AN EXPERIMENTAL SETUP TO DEVELOP RFI MITIGATION TECHNIQUES FOR RADIO ASTRONOMY

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Abstract

Increasing levels of Radio Frequency Interference (RFI) are a problem for research in radio astronomy. Various techniques to suppress RFI and extract astronomical signals from data affected by interference are being tried out. However, extracting weak astronomical signals in the spectral region affected by RFI remains a technological challenge. In this paper, we describe the construction of an experimental setup at the Raman Research Institute (RRI), Bangalore, India for research in RFI mitigation. We also present some results of tests done on the data collected using this setup. The experimental setup makes use of the 1.42 GHz receiver system of the 10.4 m telescope at RRI. A new reference antenna, its receiver system and a backend for recording digitized voltage together with the 1.42 GHz receiver system form the experimental setup. We present the results of the characterization of the experimental setup. An off-line adaptive filter was successfully implemented and tested using the data obtained with the experimental setup.

Introduction

Radio frequency interference (RFI) is a growing problem for research in radio astronomy. The ITU (International Telecommunication Union) has defined and regulated the usage of the radio spectrum by allocating various frequency bands for different services including radio astronomy. Since radio flux densities from cosmic sources are typically 40 to 100 dB below those due to other services, often the out-of-band emission from other services limits the sensitivity of astronomical observations. Moreover, several radio spectral emissions from cosmic sources are present in the frequency range outside the allocated band for radio astronomy. Thus mitigating interference and extracting radio signals from cosmic sources is essential for advancement of research in radio astronomy.

Several RFI mitigation techniques have been developed and applied for radio astronomy application [1], [see also 2], [3 and references therein]. For example, a blanking algorithm to excise short (a few μsec wide) pulses due to distance measuring equipment on astronomical data at frequencies around 1 GHz was developed and applied to data taken using the Green Bank telescope [4],[5]. A real-time adaptive cancellation technique to suppress interference in the voltage domain was developed by [6], while [7] developed a post-correlation technique, which essentially works on the power domain (i.e. after detection). The deviation of the probability distribution of the output of a telescope from normal distribution in the presence of RFI was also used to excise interference [8]. These techniques are successful to a large extent, however, RFI rejection achieved is not often sufficient for sensitive radio astronomy observations. Thus research into developing new mitigation techniques is necessary. In this paper, we describe the construction of an experimental setup at the Raman Research Institute (RRI) for developing new mitigation techniques for radio astronomy application and present some results of the test done on the data obtained with the setup.

The Experimental Setup

A block diagram of the experimental setup is shown in Fig. 1. The 10.4 m telescope at RRI was originally built for operation in the mm-wave band. A few years ago, a 1.4 GHz receiver system was added to the telescope primarily for educational purposes. The 1.4 GHz frequency band of this telescope is contaminated with RFI and hence is an ideal system to develop and test interference mitigation algorithms. We used one of the polarizations of this receiver system as the 'primary channel' to receive the RFI contaminated astronomical signal. We constructed a 'reference channel' and used the second polarization of the 1.4 GHz receiver system to connect its output to the backend. The 'reference channel' consists of a pyramidal horn antenna, coupled to a low noise amplifier (LNA) using a single linearized probe. The horn antenna and the LNA operate near 1420.5 MHz. The signal from the horn antenna is band limited to 25 MHz using a cavity filter. Both primary and reference channel outputs are further amplified and down converted to 50 MHz in the interface unit. At this stage the bandwidth is limited to 10 MHz. We modified an existing Portable Pulsar receiver (PPR; [9]) to record the digitized voltage from the two channels to a Personal Computer (PC) hard disk. The PPR further limits the bandwidth of the signals to 1.3 MHz. The signals are bandpass sampled and digitized to 2 bits before recording.

The characteristics of the components of the experimental setup were measured. The measured E and H plane radiation patterns of the pyramidal horn antenna are shown in Fig. 2. The half power beam widths of the antenna in the E and
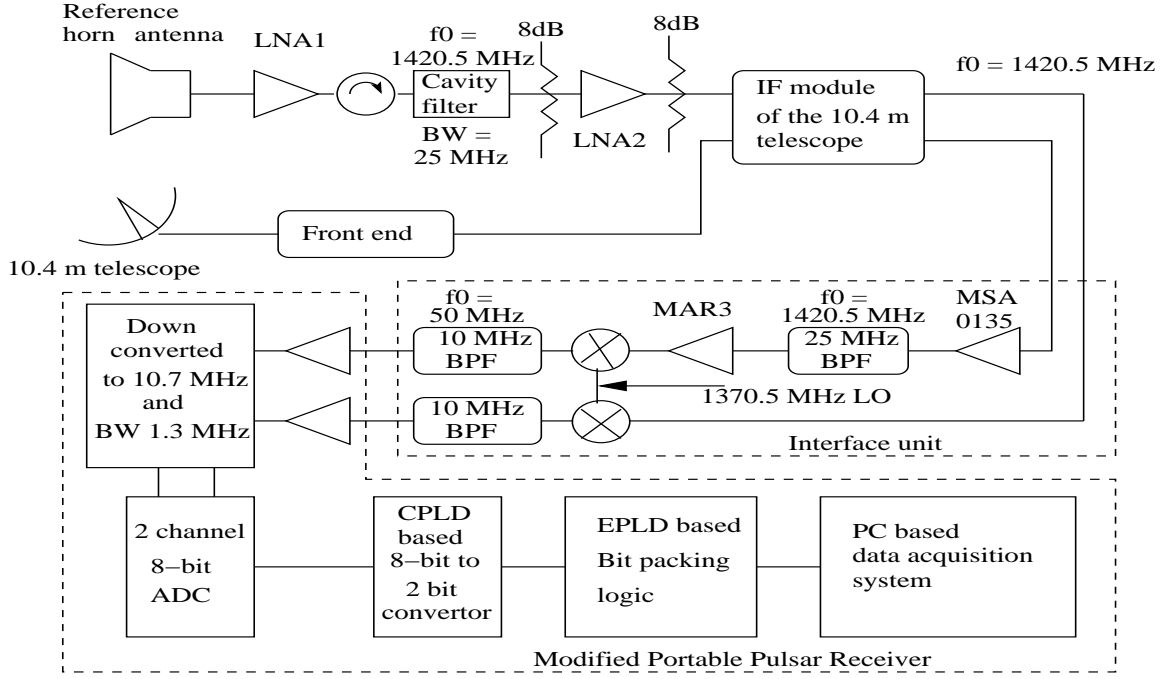
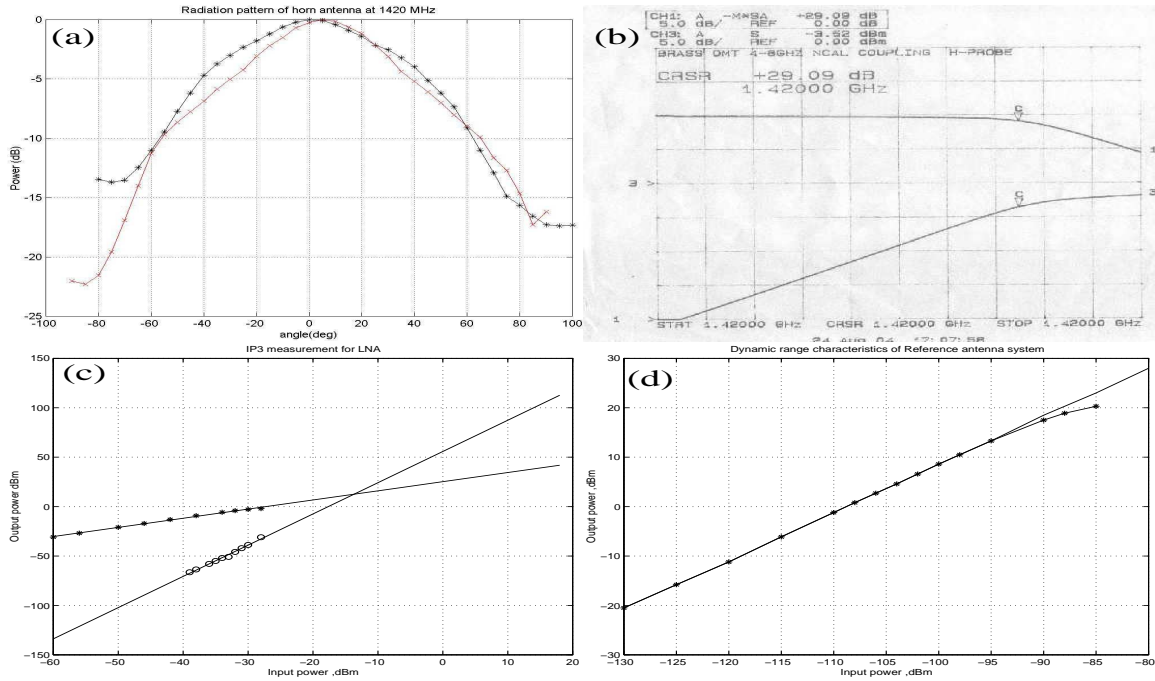Figure 1: A block diagram of the experimental setup.

Figure 2: Characteristics of the components of the experimental setup. (a) E (black) and H (red) plane radiation patterns of the pyramidal horn antenna. (b) Gain (top solid line marked 1) and output power (bottom solid line marked 3) against input power to the LNA. The marker 'c' indicates 29 dB gain, which corresponds to the 1 dB compression point. The 1 dB compression point of the LNA is -3.5 dBm (marker 'c' in the bottom curve). (c) Result of the two-tone, third order intercept point measurement of the LNA. The output IP3 of the LNA is $+12.5$ dBm. (d) Result of the measurement of the 1 dB compression point of the analog part of the reference receiver system. The measured 1 dB compression point is $+17$ dBm.
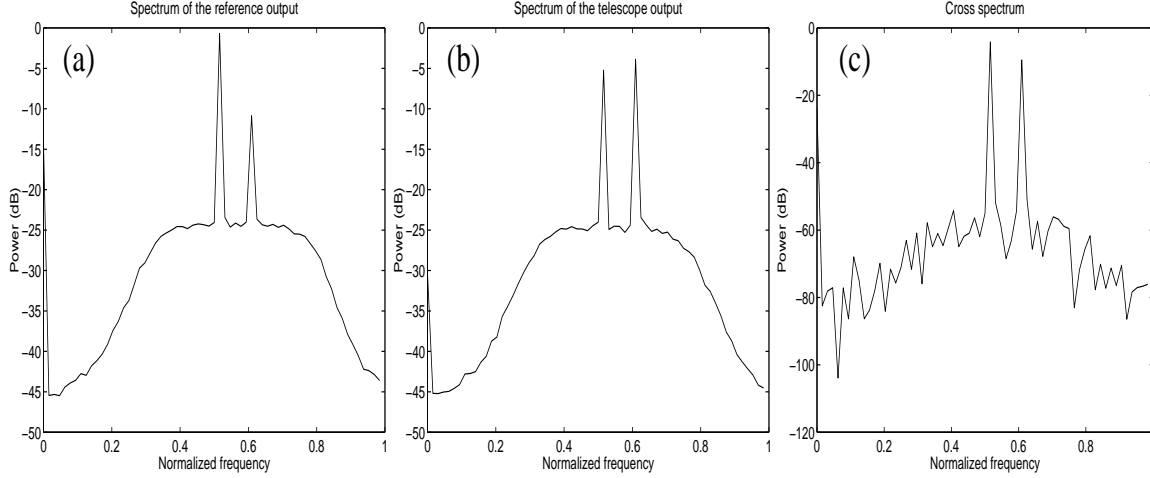
Figure 3: Spectra obtained from the data recorded using the experimental setup. Spectra obtained from the reference and telescope outputs are shown in (a) and (b) respectively. Two narrow band interference can be seen in the plots. The Fourier transform of the cross correlation of the two signals is shown in (c). All spectra are integrated for about 60 msec.
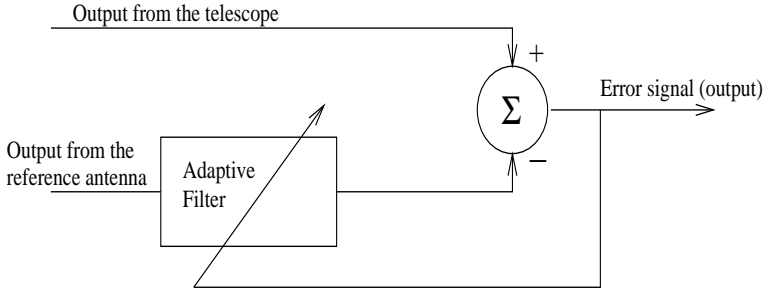

Figure 4: A block diagram of the Matlab implementation of the off-line adaptive filter. The 2 bit digitized data from the experimental setup forms the inputs to the adaptive filter. Fig. 5 shows the spectrum of the output of this filter.

H planes are 60° and 50° respectively. The LNA used in the 'reference channel' is a three stage HEMT amplifier [10], which has a measured gain of 30 dB, noise temperature of 30 K and bandwidth of 500 MHz centered at 1.42 GHz. The 1 dB compression point and the output IP3 (two-tone, third order intercept point) of the LNA measured at 1.42 GHz are -3.5 dBm and +12.5 dBm. We also measured the 1 dB compression point of the analog part of the reference receiver system, which is +17 dBm.

Preliminary Results

We recorded the data using the experimental system by pointing the telescope at different directions. Sample spectra obtained from the recorded data are shown in Fig. 3. The signals are sampled at a frequency slightly larger than the Nyquist rate (ie 1.3×2 MHz) for the purpose of producing Fig. 3. Two strong narrow band interferences near 0.5 and 0.6 normalized frequencies are present at the telescope and reference antenna outputs. The cross correlation of the two outputs confirms the common origin of both these interferences.

For testing the functioning of the experimental setup, we radiated a single tone and recorded the data from both the reference and telescope output. The recorded signals were passed through an adaptive filter configuration similar to that developed by [6]. The block diagram of the adaptive filter, which was implemented using Matlab, is shown in Fig. 4. A 60 tap FIR filter along with least mean square (LMS) algorithm was used for the implementation. The spectra of the input signals to the adaptive filter and the spectrum of its output are shown in Fig. 5. The spectra were integrated for about 100 msec. The narrow band signal near the normalized frequency 0.5 is the radiated tone. The narrow band signal near normalized frequency 0.45 is an RFI from unknown source. As seen in Fig. 5, both the radiated tone and the RFI are attenuated by the adaptive filter. The RFI rejection obtained for the radiated tone is about 45 dB. Note also that the spectral shape away from the narrow band interferences is not affected by the filtering process.
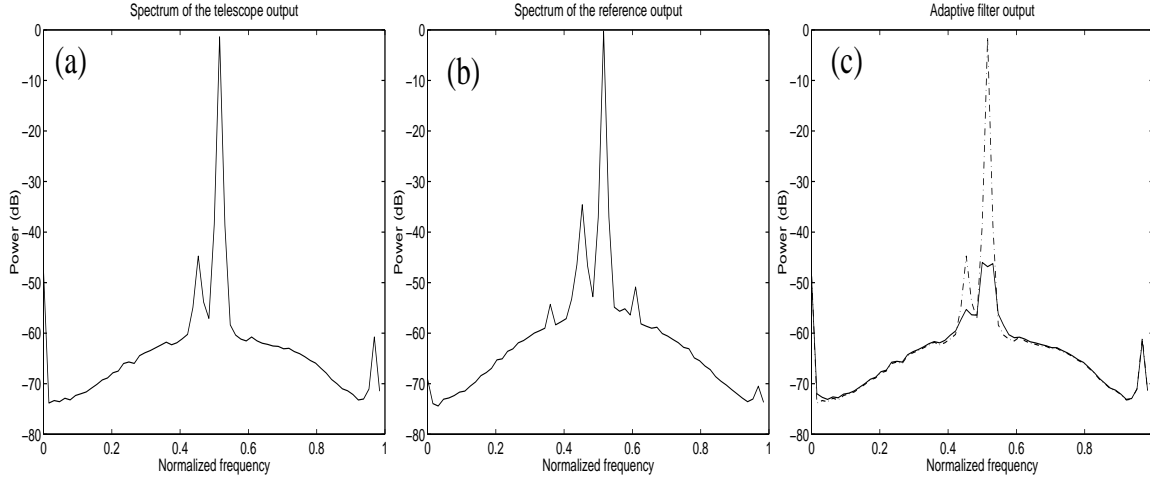
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Figure 5: Spectra of the telescope and reference antenna outputs obtained with the radiated tone are shown in (a) and (b) respectively. The spectrum of the output of the adaptive filter is shown in (c). For comparison the spectrum of the telescope output is shown in 'dash-dot' line in (c). As seen in the figure the interference is attenuated after passing through the adaptive filter. The radiated signal (near normalized frequency of 0.5) is attenuated by about 45 dB.

Acknowledgment

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